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THESIS

WIRELESS CONTENT REPURPOSING ARCHITECTURE FOR DC COMMAND AND CONTROL

by

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September 2003

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WIRELESS CONTENT REPURPOSING ARCHITECTURE FOR DC COMMAND AND CONTROL

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ABSTRACT

Damage control communications should be improved onboard US Navy ships. Current standard operating procedures are antiquated and should be replaced. Wireless networks are an improvement over the status quo and mobile devices offer new capabilities that greatly improve the situational awareness for team members.

In this thesis, a system architecture is designed for a damage control wireless local area network with Commercial-Off-The-Shelf components. This makes the system affordable and prevents previous miscommunications from occurring.

The ability to view the information on different devices effectively is a unique problem to the mobile user and requires the use of content repurposing at the server.

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I. INTRODUCTION

A. INTRODUCTION

All Navy ships must accomplish many tasks to carry out their assigned missions. These include propulsion, electrical power generation, weapon delivery, small boat operations, and a myriad of others. However, the most important of these tasks is keeping the ship afloat, and to do this, damage control (DC) plays an important role for all Sailors. DC is considered such a critical activity that when Sailors check onboard a ship, they all receive DC training and then complete basic DC as their first qualification. Everyone, regardless of their rate, is responsible for keeping the ship afloat.

However, current DC processes use antiquated technology and methods to communicate, such as sound-powered phones, radios, and grease pencils with laminated drawings. This is unacceptable, since the speed of information dissemination is a major factor in the effectiveness of the decision making in DC. Slow and inadequate communication leads to significant problems which impede effective DC, including low situational awareness and delayed action. The use of mobile devices and wireless communication can help alleviate many of the existing problems and enable the DC organization to be better organized for a more concerted and rapid response. An additional benefit of this improved communication can be reduced manpower needs for DC.

Previous thesis work by Sayat researched the feasibility of a wireless LAN (WLAN) and pen-based computers to enhance damage control efforts and log taking onboard US Navy ships. He found that the benefits of such a system outweighed the negatives and recommended it for future research [1]. Rothenhaus in his 1999 thesis came to the same conclusions [3].

The technical focus of this thesis is to develop an architecture that supports large-scale, multi-device, and multi-network applications. Our application focus is achieved by developing applications that enhance the user's capability and productivity while reducing the risk.

For this research, we chose to use a personal data assistant (PDA) with a built-in camera and 802.11b networking capability using a wireless card. For real-life deployment, however, a ruggedized PDA will be required so that it can survive through the harsher environment of DC at sea.

1. Mobile Devices

Mobile devices such as PDAs, mobile phones, and Smartphones have become tightly interwoven as an important part of everyday lives. In the past, these devices acted as Personal Information Management (PIM) tools but rarely anything more. Now, because of recent advances, wireless networking capabilities such as 802.11 and/or Bluetooth come integrated with many of the devices. These new mobile devices have potential uses that greatly surpass PIM.

A key reason for the massive under-utilization of mobile devices is the lack of applications that deliver a significant value to users [4]. Application development must begin with a requirement in the context of the users' task. For the successful development of a mobile application, one must understand the application domain, capabilities and limitations of the devices and networks used, dynamics of mobile use, and build a complete solution scenario while keeping the human factors in mind [4].

Mobile devices offer many benefits to the user. They are portable, integrated, lighter, and offer long battery life. They provide great transmitting and receiving devices for small amounts of information.

2. Wireless Local Area Networks (WLANs)

WLANs add an extra dimension that wired LANs could not offer which was mobility. With wired LANs users are limited by the length of the connection. With WLANs people can move throughout a building without being connected to a specific point in the building as long as they reside within the range of a wireless access point (WAP) [Note: In this paper WAP will refer to the wireless access point and not Wireless Application Protocol]. This capability has made 802.11, the most common wireless networking protocol, very popular with users.

These WLANs work by using electromagnetic waves to deliver energy from one device to an access point. The access point is connected to the network by a standard Ethernet cable. IEEE (Institute of Electrical and Electronics Engineers) 802.11 is a shared, wireless local area network standard. It uses the carrier sense multiple access (CSMA) / collision avoidance (CA), medium access control (MAC) protocol. This standard allows for both direct sequence (DS), and frequency-hopping (FH) spread spectrum transmissions at the physical layer. The maximum data rate initially offered by this standard was 2 megabits per second. A higher-speed version, with a physical layer definition under the 802.11b specification, allows a data rate of up to 11 megabits per second using DS spread spectrum transmission. The standards committee in IEEE has also defined physical layer criteria under the 802.11a specification. This is based on orthogonal frequency-division multiplexing (OFDM) that will permit data transfer rates up to 54 megabits per second [5].

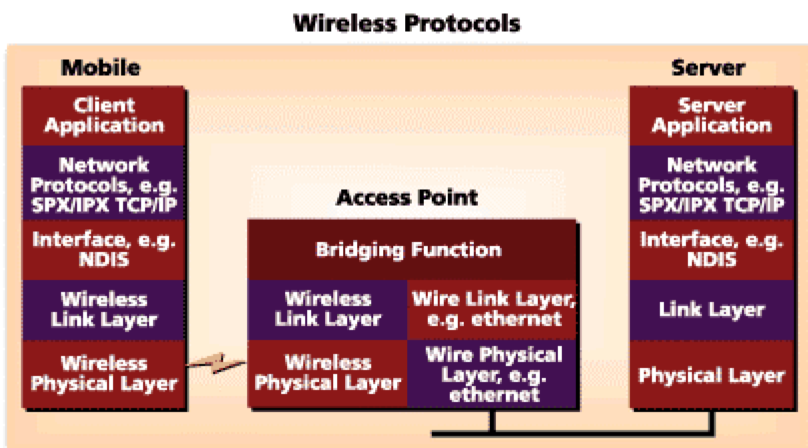


Figure 1.1 Wireless LAN Logical Diagram(From Ref. 6)

WLANs offer the following benefits over traditional wired networks:

- Mobility – Users can be anywhere within the range of an access point associated with their system and receive needed information.[1]
- Cost – Initial cost of installation may be more expensive but overall cost and system life cycle maintenance should be lower. Also, if machines are moved then manpower is not needed to change cabling.[1]
- Installation Flexibility – Wireless networks allow users to use devices where cables cannot reach.[1]
- Scalability – Users can enter a network as long as they use the proper SSID and WEP key. No other routing of cable or wires is needed.

3. Mobile Devices and Wireless Networking

People in the medical profession already take advantage of PDAs being connected wirelessly to a network server. These doctors connect their Palm devices through a web browser to a web server to receive information about patients. In Florida, a heart surgeon turned to a startup company named Teges which allowed doctors to receive the patients' information from inside the hospital. They also now have the ability to input photographs of patients which can be used for many purposes. For example, the main purpose of the image sharing tool was to monitor babies in the Intensive Care Unit [7]. This networking ability allows the Dr. Burke to "keep one hand on the sick baby and one hand on the sick baby's data". Their process is now faster because the doctor does not have to go back and get new files from the nurse every time. Doctors only have to use their mobile device to log into their network. This saves numerous man-hours and is more efficient medical care.

Advances in networking and mobile device technology have begun changes in war-fighting capabilities never seen before. For example, DARPA has created the first generation device called the Handheld Multimedia Terminal. Its main purpose is to identify friendly forces positions thereby limiting friendly fire engagements for ground units or groups. These devices are networked together and do not require a set infrastructure to be in place [8]. The methods of using real-time networked information for DC purposes will be similar to how an Army or Marine unit networked together would attack a target. The information the DC leaders receive allows them to make a decision on the best points of attack. This will allow leaders in DC organization to effectively send the DC team with the reduced manpower necessary due to the raised situational awareness.

B. OBJECTIVE

The objective of the thesis is to develop a system architecture to support the DC task aboard Navy ships. The architecture should:

- -Support mobile devices communicating over 802.11b WLAN, and
- -Allow real-time transmission of rich content that includes images and text.

C. ASSUMPTION

Major assumption: 802.11 RF signals will effectively propagate throughout a US Navy ship for effective data transfer. This is a reasonably safe assumption as an 802.11b network was installed on USS HOWARD (DDG-83) for testing purposes and was successful [9]. Also, previous thesis work done at NPS by McConnell [2] shows the data rate transfers of wireless networks onboard US Navy ships.

D. CHAPTER OUTLINE

The thesis is organized as follows:

Chapter II discusses previous work done in this field. It also provides a detailed background on how a ship combats a fire DC emergency and content repurposing. Chapter III discusses system design and architecture. Chapter IV assesses human factors that are involved when using mobile computing devices. Chapter V is the conclusion and discusses possible follow-on work.

II. BACKGROUND INFORMATION AND RELATED WORK

The first section of this chapter discusses background information that is essential to understanding how mobile devices and network enhance the DC decision making process. The subsequent sections give short summaries of previous research accomplished at the Naval Postgraduate School in my area of research.

A. INTRODUCTION TO CURRENT SHIPBOARD DC PROCEDURES

DC is a vital area onboard any ship, but especially onboard the warships of the US Navy. In recent history, effective damage control saved the following ships: USS STARK, which was hit by Iraqi missiles, USS SAMUEL B. ROBERTS which hit a mine, and USS COLE, which was attacked by terrorists. Obviously due to the nature of the military, a high premium is placed on DC readiness. During an emergency, there is a risk of a fire, flood, or other emergency spreading quickly and uncontrollably. To prevent this from occurring, the leaders in the damage control decision making process must have the information they need quickly in front of them to ensure they have proper situational awareness and can quickly pass the information to the correct personnel.

All Navy ships have similar procedures for combating emergencies such as a fire in an engine room. These procedures will be outlined so that the reader can understand the flow of information and can then understand how mobile devices may facilitate the DC process.

As soon as fire is discovered, it is announced over the public announcement system. The Damage Control

Assistant (DCA), who leads the overall DC organization during these emergencies, assumes responsibility for over all DC efforts in Damage Control Central (DCC). DC Repair Stations (DCRS) are storage lockers and nodes in the command and control of DC efforts. The repair station personnel assemble concurrently once the alarm occurs. The DCA orders the investigators to begin their search for damage.

Reports from the repair station begin to flow into DCC notifying them of the status of the fire, status of personnel, etc. If required, the DCA may order the setting of mechanical and electrical isolation of compartments. The personnel who accomplish these tasks normally either memorize the information or carry laminated sheets of paper in a notebook which identifies the valves or circuit boards that need to be operated to isolate the affected compartment. The DCRS then sends out personnel to set boundaries to prevent the spread of damage. RL teams are deployed to the scene after dressing out in their appropriate ensemble. If personnel must activate a breathing apparatus in order to enter a smoke filled space, the time of activation must be reported to DCC from the repair lockers. The On-Scene Leader (OSL), who is in charge of the fire party and the area surrounding the fire, reports these times to the DCRS and any other important events using handheld radios known as Wire Free Communication Systems (WIFCOMs).

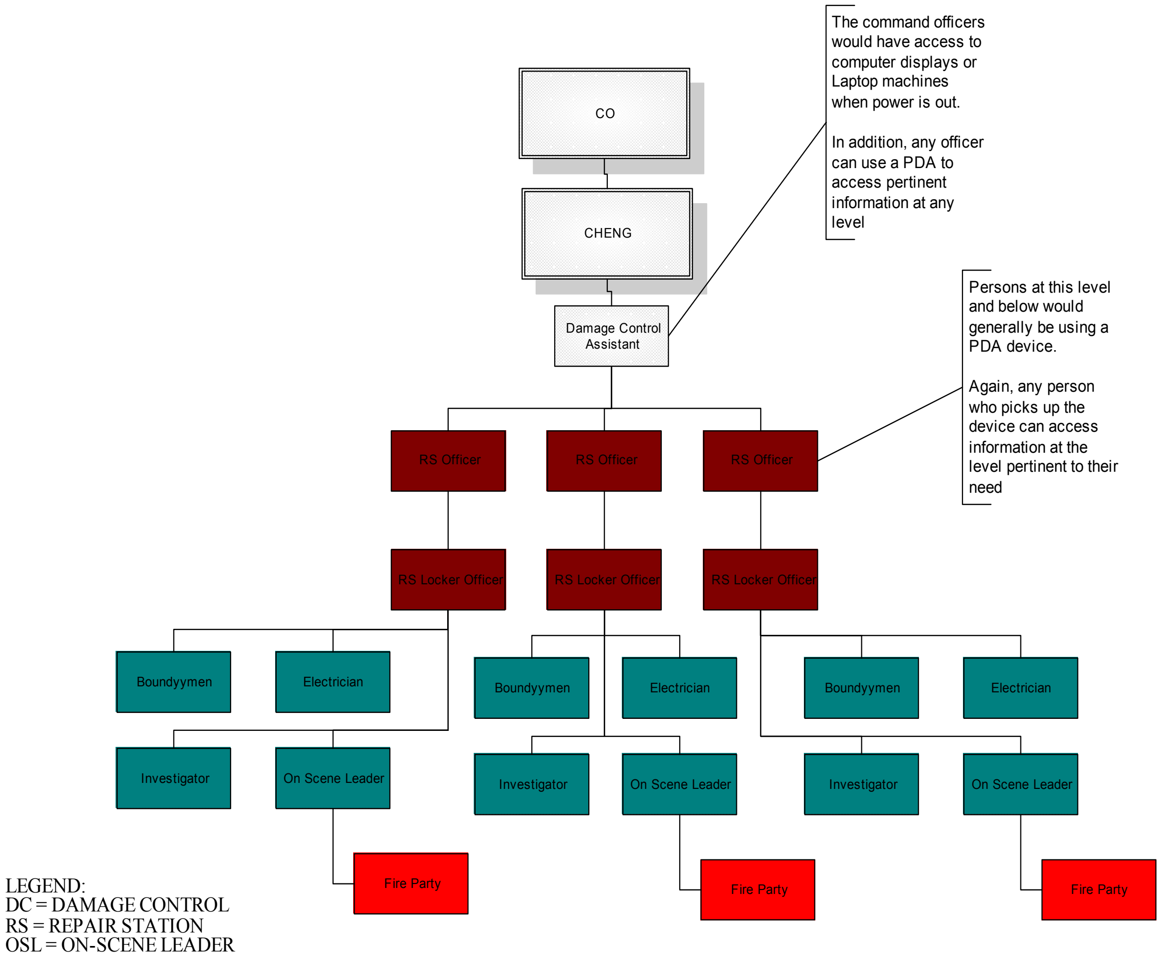


Figure 2.1 DC Organization

The DC leadership must preserve situational awareness of all damage in their area of responsibility. OSLs must maintain the overall picture of the damage control efforts in their area and pass this information to the DC chain of command. OSLs pass information regarding the status of the emergency to the DCRS, who in turn pass it on to DCC so that the DCA can maintain situational awareness of all emergencies on the ship. DCC also passes this information to the other DCRSs in the event DCC is lost. All the communication between DCRSs and DCC is made using sound-power phones, which sometimes require numerous attempts to pass the verbal information correctly. The DCA processes each message that comes to DCC and then other personnel transfer that information to laminated drawings using grease pencils so that all can see the current status of the emergency. These sheets can be very hard to read and understand.

Throughout all this, investigators continue to search the ship for the spread of damage and ensure boundaries are set and then report the information using WIFCOMs. Fire parties eventually will contain the spread of damage, and finally put the personnel will put the fire out. After the damage has been controlled and the fire put out, the repair state personnel overhaul the affected area. They begin pumping out any excess water and smoke out from the ship.

It is easy to see the large volume of communication required for even the simplest casualty. Additionally, this communication uses out-dated methods, which increase the likelihood that many messages must be repeated or will be misunderstood. The same damage control tasks can be accomplished in a more efficient and predictable manner by integrating PDAs and wireless LAN (WLAN) into the ship environment. The following scenario describes a new implementation.

In the new scenario, the OSL would carry a mobile device such as a ruggedized PDA or a tablet PC connected via a WLAN into the Damage Control System (DCS). Investigators and electricians carry a PDA with a built-in camera with annotation features and wireless card while command and control nodes such as the DCA and DCRS Officers have portable laptops connected to the WLAN that have schematics of the ship. Thus, there is no requirement for communications using difficult or ambiguous methods, and each message must only be entered once and is automatically transmitted to all the stations which require the information.

In the above scenario, one can see several areas where the process is more efficient compared with the current practice. During topic development, the goal was to use technologies that were readily available on the open commercial market today. This assisted us in proving that enormous improvements could be made by using only commercial-off-the-shelf (COTS) equipment.

B. CURRENT NAVY POLICY ON WIRELESS NETWORKS

The Pacific Fleet Commander has stated that not enough is known about wireless technologies so until further notice, WLANs are no longer authorized except on certain ships as test platforms. This was due to some security concerns while using wireless technologies. With that in mind, however, the Navy values any technology that increases efficiency and lowers manpower requirements. An example of this is onboard USS HOWARD (DDG-83). engineering machinery connects to the ship’s local area network (LAN) via a 802.11b wireless connection so that ship’s company may access the readings from a LAN computer.[9] This concept, called Total Ship Manning, means that enlisted personnel now do not have to go down into the engineering spaces unless a reading is not within standards.

C. DAMAGE CONTROL AND LOG TAKING USING WLANS

Turkish Army 1st LT Hanceri Sayat conducted thesis research on damage control and log-taking using Java for shipboard wireless LANs in December 1999 [1]. This section summarizes the importance of using the Java architecture for this systems network.

1. Java Architecture Importance

"Write Once, Run Everywhere". That is what the creators of Java were thinking as they worked to create a language to run on a distributed network. Sun Microsystems developed a high level programming language in 1991 called Oak. The intention was to create a small computer language that could be used for devices that did not have much power or memory. Constraints for the task were for the language to be relatively small, generate tight code, and make the language architecture neutral due to the different central processing units (CPUs). In 1995, Oak's name changed to Java. Java was subsequently transformed to take advantage of the World Wide Web (WWW).

Java now is made for writing client/server and networked applications. This object orientated language was created to be platform independent. It is important to distinguish that Java is two different things with one being the language and the other being the Java Virtual Machine. The Java architecture is shown below:

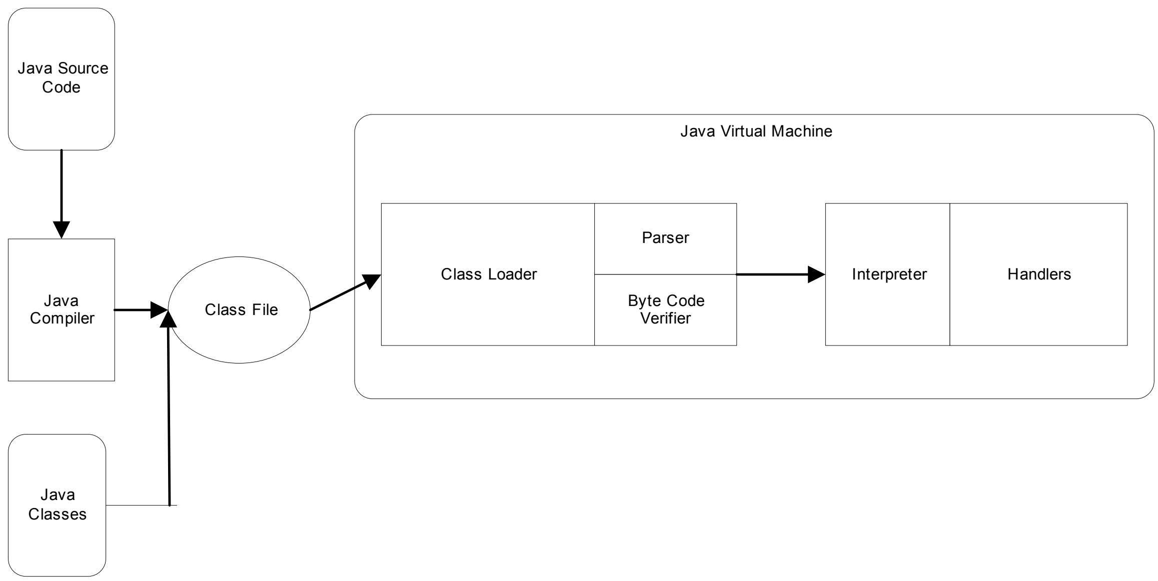


Figure 2.2 The Java Architecture (From Ref. 1)

The Java Virtual Machine (JVM) plays an important role in the architecture. They do not physically exist but acts as a program emulating a software processor.

Java's advantages are that it is simple, secure, high performance, multi-threaded and distributed. It is simple because no unnecessary features are added and program administration is minimized due to automatic garbage collection. Java was designed to make writing bug-free code easier. Object-orientated programming means that code writers will concentrate their efforts on the data in applications and methods that manipulate that data rather than thinking in terms of procedures. Java is designed to work in a heterogeneous networked environment. This platform independence is needed when using different hardware architectures. Security is an issue for java because of its main use in a network. It offers high performance because it uses a scheme that can run at full speed without needing to check the run-time environment. Java can be compiled as quickly as C++ due to its compiler. Because the language is inherently multi-threaded that allows multitasking to occur.

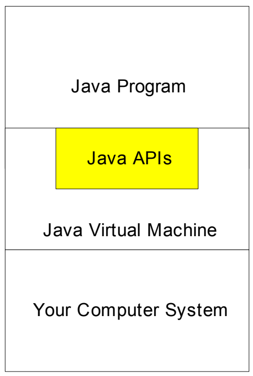


Figure 2.3 The Java Stack (From Ref. 1)

a. Applets

Java Applets are small programs that are designed to run inside other applications. Applets work well with networks that work with the WWW because once downloaded, execution is quick on the user’s browser. The Application Program Interface (API) is provided in java.applet package. Applets can perform the following tasks:

A. Applets can normally make network connections to the host they came from.
B. Applets running within a Web browser can easily cause Hyper Text Markup Language (HTML) documents to be displayed.
C. Applets can improve public methods of other applets on the same HTML page.
D. Applets that are loaded from the local file system have none of the restrictions that applets loaded over the network do.
E. Although most applets stop running once the user leaves their page that is not a necessity. [1]

Applets do have some restrictions, however. Ordinarily they cannot write or read files on the computer that they are executing on, and they cannot make network connections except to the originating host.

b. Servlets

Servlets are “a standard approach to extending the server functionality without the limitations of CGI-based or server-specific approaches”. The servlet can be thought of as a platform independent 100% Pure Java server-side applet. They run inside the Web server and respond to requests made from browsers. A plain HTML document that a Web server retrieves is static; however, a servlet is executed so that it may put out dynamic information.

Advantages of using servlets include platform independence, high performance, extensibility, easier development, better error recovery, portability, and modularity.

D. COMPONENT TESTING FOR WLANS

This section summarizes a NPS thesis done by McConnell in 2000. It provides background information in Wireless LANs, shipboard radio frequencies (RF).

1. WLANs

WLANs utilize RFs to transmit and receive information. These electromagnetic waves communicate the information without relying on any physical structures in between except the WAP and the communication device. The information being transmitted is modulated onto a radio carrier frequency. Modulation is defined as varying the frequency, phase, or amplitude of the carrier wave. After the data is received at the WAP from the air medium, the signal is demodulated and regains its original form. That data then proceeds along the wired portion of the network.

Most WLANs utilize what is known as spread spectrum (SS) technology. This technology is a wideband radio frequency technique developed by the military for use in reliable, secure, mission-critical communications systems. SS trades off bandwidth efficiency for reliability, integrity, and security. SS relies on the receiver knowing the parameters so they may find the signal in the air medium otherwise the receiver will see that data as background noise [2]. The two main types of SS are direct sequence and frequency hopping known as DSSS and FHSS respectively.

The IEEE created the 802.11 standard in February of 1980. This standard specifies Carrier Sense Multiple Access with collision avoidance (CMSA/CA) as the fundamental access method. Basically, it is a “listen before talk” mechanism meaning that the station wishing to transmit must first check to see the medium is clear before it is able to transmit. This scheme implements a minimum time gap between frames from a given user. Once a frame has been sent from a transmission station, it must wait until the time gap completes before transmitting again. Once the time has passed, the station selects a random amount of time to wait before checking the medium to verify it is clear to transmit. If the channel is busy, another waiting time is selected which is shorter than the previous waiting time. This prevents one station from taking all the bandwidth.

A single access point can support multiple users; however, the more users that access the WAP, the lower the data rate will be for transmission. Types of antennas and location of the antenna are important because different antennas transmit more effectively in certain directions. For example, one would not use a yagi antenna if attempting to transmit to a wide area because the edges of the field would not receive adequate coverage. Another antenna type must be selected.

When roaming on a WLAN, an adapter must be installed into your device. They provide an interface between the client network operating system and the airwaves. The details of the transmission are handled by the Medium Access Control (MAC) and Physical layers of the Open Systems Interconnection (OSI) model illustrated below and are transparent to the network operating system:

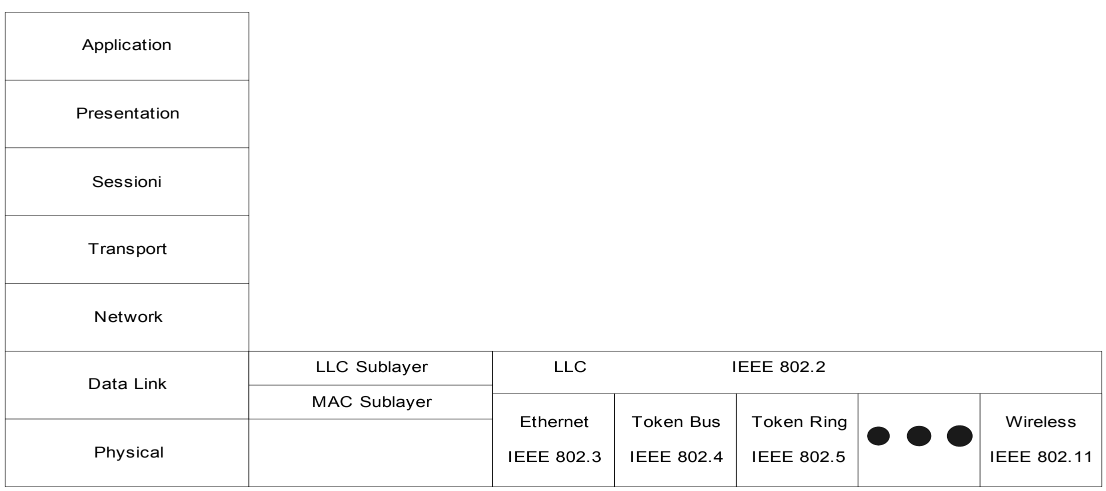


Figure 2.4 OSI Model (From Ref. 2)

2. Characteristics of Shipboard RF Channel

Many impediments exist onboard naval vessels that preclude direct signal path propagation and heighten multipath signal propagation. Multipath propagation occurs when an RF signal takes different paths when leaving from the source to a destination node [10]. When this occurs, it is deemed multipath fading and refers to a signal's random fluctuations or fading due to multipath propagation. The presence of multipath components highly degrades channel performance and complicates analysis. Direct propagation rarely exists in a shipboard environment.

3. Shipboard RF Channel Classification

Due to the compartmentalization of the shipboard environment, the assumption that fading will occur is acceptable. These characteristics are dependant upon the geometry between the transmitter and receiver. The shipboard RF signal should exhibit slow fading characteristics.

The primary method to minimize susceptibility to deep fading is SS modulation.

E. RF PROPAGATION IN DAMAGE CONTROL SCENARIOS

Christos Deyannis and Dimitrios Xifaras, in their 2000 NPS thesis, measured 2.4GHz propagation through diesel and heptane fire, smoke, and steam in the machine space of ex-USS SHADWELL. They found that the largest attenuation occurred when the water-mist fire extinguishing system was activated. On average, the excess loss reached the order of 0.1 dB/m. There was no ionization from the hydro-carbon fuel fire to block the 2.4 GHz channel. A more in-depth explanation of their thesis may be found at the NPS Library or online [11].

F. ISSUES WITH USING VARIOUS TYPES OF MOBILE DEVICES

This section covers the importance of content repurposing and the need for it when using a variety of mobile devices.

1. Introduction

When the Internet was first created, content available on the WWW was almost exclusively accessed by using personal computers. Now, people access online services using a multitude of devices such as cellular phones, PDAs, pagers, etc. More than 600 different device profiles are available for accessing online content [4]! Slow-speed wireless, 2.5/3 G wireless, dial-up and local area wired and wireless, and high-speed wired networks connections enable these devices to transmit and receive data. Because of significant differences in form factor and network connectivity, accessing content designed for desktop computers does not work well with mobile devices. For example, a large image displays very well on the screen of a desktop computer, but when it is shrunk to fit small screen of a PDA, it may lose important information. Also, web pages designed for the screen of a desktop need to be split into multiple small pages for PDAs. This requires extensive rework of the original design.

Content repurposing tackles this problem by taking content designed for a particular scenario and automatically repurposing it to fit another. Fundamental to this approach is the need to maintain a single copy of the content in its original form and to repurpose the content to fit the desired scenario in real-time and in an automated fashion [4].

There are significant challenges in developing systems that deliver media-rich information to a variety of handheld devices. All handheld devices are not created equal. While device manufacturers strive to distinguish their products from that of their competitors by adding, improving upon or even removing device features, standardization efforts attempt to establish some common ground. Between these “ying and yang” forces, a middle ground emerges where both the diversity and the standards are significant.

Devices vary in display size, resolution, color capabilities, image and sound, table capabilities, and navigation methods available. Technologies delivering content to these devices must conform to standards while at the same time acknowledge and respond to the device diversity. Schilit, Trevor, Hilbert and Koh (2002) provide an introduction to the issues in delivering web content to small devices.

2. Current Procedures

There are several procedures currently in use for fitting information onto a small display:

1. Scaling: Scaling when used with devices of high resolution such as Pocket PC provide a user experience similar to desktop browsing. However, scaling reduces readability and ease of use [12].
2. Manual authoring: This technique involves the content provider such as a professional Web or graphic designer tailors the Web content to fit their particular device [12]. Labor intensity makes this option infeasible. Other problems in this method

include the facts that it is expensive, takes too much time, and leads to multiple, inconsistent versions of the content.

3. Transducing: This is automated technique that translates HTML and images into another format. The client device can indirectly request the data through a proxy system. Benefits of this method include cost effectiveness and allow access to content that web providers do not manually author [12]. This means that the personnel running the user interface do not have to spend the manhours to creating a website for each specific device.

4. Transforming: Transforming systems modify content to transform the structure or experience of interacting with the content. This system will modify a page layout by partitioning it into sub-pages and adding links so that the user may navigate through them [12].

5. Transcoding: Content is changed to a more appropriate representation such as reduced in size, cropped to eliminate details, or converted to monochrome. It would also provide the user with information on the original content without straining the client or network capabilities [13]. Transcoding removes unessential or unrenderable data in order to meet goals such as bandwidth reduction. This procedure would occur at a proxy.

G. CONTENT REPURPOSING

Content repurposing allows for different formats of information to be displayed on a variety of platforms without having to write multiple code.

As explained above, a simple approach to matching content to device capability is to *transcode* the content. For example, large images best viewed on PC screens can be reduced in size, converted to monochrome or changed in format so that they can be viewed on the small screens of PDAs. Such transcoding is often implemented at a “non-transparent” proxy. This proxy looks at the device profile, as defined, for example, by User Agent Profile (WAP Forum 2001), and transcodes the requested content to match the device profile. The process of transcoding, however, is not the best way to transform content. While it pays attention to the device profile, it does not pay attention to the details of the content. Most large, complex images, for example, when shrunk to fit a small PDA screens, will display poorly.

What is missing from simple-minded transcoding is the ability to understand the content so that appropriate transformation techniques can be applied to the source content or the most appropriate form of the content may be selected, where multiple forms of the source content are available. A more general process called *content repurposing* covers these details (Singh 2004). Content repurposing tackles this problem by taking content designed for a particular scenario and automatically repurposing it to fit another. Fundamental to this approach is the need to maintain a single copy of the content in its original form and to repurpose the content to fit the desired scenario in real-time and in an automated fashion.

Content repurposing issues for images from the engineering domain are explored in detail in Kasik (2003). Ma and Singh (2003) have focused their attention to preserving thin line structures in large engineering images, graphs, charts and maps as they are scaled to fit small screens. Maheshwari, Sharma, Ramamritham and Shenoy (2002) discuss the problem of matching client requests for content by cached transcoded results. Instead of tagging images with explicit features, they subdivide entries based on a small set of client categories. Our approach, as will become clear later in this paper, relies on tagging of content and then repurposing it in real-time to match client capabilities.

In their server-directed transcoding system, Knutsson, Lu, and Mogul (2002) use guidance from the origin server to the transcoding system, possibly sitting at proxy, about whether and how to convert between content representations. In their system, they include more aggressive image transformation such as cropping of images. Unless done very carefully and with the full consent of the content author, such transformation runs the risk of changing the semantics of the content.

When it comes to streaming content such as video, content repurposing issues become more complicated by the fact that it is not only the device but also the network characteristics that play a significant role in the user experience. For an acceptable user experience, video experience must not be interrupted because of fluctuations in bandwidth. Vasudevan, Singh and Jesudoss (2002) and Vasudevan, Thum and Singh (2003) propose a scheme to scale video to match the device and network capability. Instead of dropping frames randomly, they analyze video to rate video frames and segments on their relative importance to the semantics of the content, and decide what to ship and what to hold back. Tripathi and Claypool (2002) use content-aware scaling of video based on motion and other appropriate factors. Their approach does not adapt to the client capabilities.

So content repurposing allows for the original content to remain at the server and then different versions of it will be shipped to different devices. The data requests will be tagged so that when they reach the server, it knows what to send to the device. The possibility exists that different devices could enter into the DC network, so content repurposing is a tool that allows for personnel to receive the best quality information available but is tailored to maximize their user experience depending on what device they are using.

III. SYSTEM DESIGN AND ARCHITECTURE

This chapter describes the thought process leading to the system design and architecture. The first portion will describe the system requirements. Next, the paper describes the mobile device chosen for the system. Then the software for the system will be discussed, and last hardware requirements will be mentioned.

A. SYSTEM REQUIREMENTS

This system must perform in a unique situation compared to other computer networks. It must be able to meet the following criteria:

- -Operate in a shipboard environment. The large amount of steel in a shipboard environment significantly reduces the range of electromagnetic transmissions. Also, equipment must be more ruggedized to meet shipboard and DC needs such as resistance to heat, salt, and water.
- -Multiple users. The system must support multiple users in a time-critical situation such as a DC.
- -Different types of mobile devices. Many different types of mobile devices exist today. The future seems to be even more heterogeneous. All of these devices must be compatible with the DC WLAN. These devices like desktop computers are increasing their capabilities at such a fast rate that we cannot stipulate that only a minimal number of devices be used if we want the most effective devices for the Sailors.
- -Resilience. The system must be able to continue operating even if part of the system is inoperable due to damage, power loss or other circumstances.
- -Scalability. This system must be able to fit various different system topologies to meet specific applications and installations. Configurations, therefore, can easily change from a small network with only a few users to a large network with multiple users [1].
- -Mobility. Users anywhere within the ship must be able to transmit and receive information which is not possible when using only a wired network.

- Multi-media capable. Users will have the capability to send and receive multi-media transmissions.
- Security. The system must meet all US Navy standards in terms of EM emissions and be safe from hacking.

B. MOBILE DEVICE

As mentioned in Chapter I, the capabilities of mobile devices, especially their ability to transmit and receive multimedia data, are pivotal to the success of the system designed in this thesis. This section discusses the rationale for choosing a mobile device for this system.

There are many different PDAs available in the market, with a wide variety of capabilities and functionality which we had to balance in choosing one. The biggest design decision is choosing which operating system we want our mobile device to use. Today's PDAs use many different OSs, but PDAs based on the Palm OS dominate the market. In addition, since Palm PDAs have been in use for many years, their design has been revised several times over to make them user friendly. Therefore, we decided to use a PDA based upon the Palm OS.

Other decisions are not as critical as the OS, but nonetheless are important in the final performance of our system. While many PDA's are beginning to have cameras which can be attached, a PDA with a built in camera gives advantages in interoperability and ruggedness. The camera should also be able to take high resolution pictures in a format which can be used by many applications. Additionally, the chosen PDA must be lightweight and be small enough for investigators to easily store and transport as they respond to emergencies. It should also have long battery life, because during some casualties, electrical power may not be restored for a considerable time and failure of the mobile device due to power loss is unacceptable.

1. Sony Clie

Figure 3.1 Sony Clie PEG-NX70(From Ref. 17)

Based upon these criteria, we decided to use the Sony Clie PEG-NX70. This is a Palm OS based PDA, but its display has more of a Windows CE “look and feel” to it, which will make it easier for a wide range of users to use with minimal training. Additionally, the Clie is one of the first PDAs to incorporate a camera with a flash into the design of the PDA. The device is lightweight and fits easily into the pants pockets of a uniform and the device only weighs 220 grams. Given its exceptional ergonomic design and the built-in camera, the Sony Clie was a natural choice as our primary mobile device for the DC investigators.

The Clie uses a Lithium Ion battery, which is the longest lasting out of the most popular rechargeable batteries currently available in the market. Battery life ranges between one hour to approximately six hours of continuous use when using functions outside of PIM such as the camera and voice recording function.

The Sony Clie’s built-in camera has a maximum resolution of 1600 x 1200 pixels (2 Mega pixels) in the commonly used JPEG format. It is also capable of taking short video clips at a resolution of 160 x 112 pixels and replaying them at 320 x 240 pixels [14]. Unfortunately, Sony does not distribute Application Program Interfaces for its camera, which means programmers cannot easily create new applications for the users of the device.

Like any Palm OS based PDA, the Sony Clie can be programmed either using C++ or Java. There is a Software Development Kit available at www.cliedeveloper.com for the PDA. However, in programming the Clie there are many little nuances that have to meet both Sony standards and the Palm OS standard. For example, in order to transfer data, the programming statement had to be written in an exact method, otherwise it will not work.

The Clie also has several other features other than those we looked at which will improve its performance. User input can be done in many different ways such as stylus input, jog-dial, touch screen, and built-in keyboard. This gives the user numerous ways to input data if in certain situations can not use the normal stylus entry. The Clie’s color screen is unique in that it can rotate 180 degrees to protect it when being carried in a closed position, but then rotated open when in use. The screen is an LCD (TFT) which is 5.5 inches diagonally.

The Sony Clie comes with 16MB of internal memory and also has 16 MB of ROM. It also supports the Sony memory stick, which is portable memory and can be inserted into any Sony laptop or camera. Sony Clie’s uses an ARM processor running at a speed of 200 MHz.

2. Wireless Card

The Clie has two ways to connect wirelessly with other devices. The first is using WIFI (802.11b) to connect to a WLAN with a standard maximum data transfer rate of 11 Mbps. The PEGA-WL100 is the standard 802.11b wireless card made by Sony for their Clie line of products. The product is WIFI certified so it will be compatible with other WIFI certified devices. However, for the browser to operate at its maximum capability using WiFi, 6 MB of internal memory must be free. For other WLAN connections, Clie has built-in Bluetooth capability. The current short range of Bluetooth, however, does not allow it to be a viable option for this DC network.

One problem discovered with data transfer is that when transferring over 1 MB using this card is that the transfer may be interrupted. This is due to limitations in the Palm 5.0 OS [20].

C. DEVELOPMENT OF THE SYSTEM

The architecture of this system should support multiple users using PDAs, laptops, and new upcoming mobile devices. The users must have the ability to send and receive the following: annotated images, text, voice, drawings, and multimedia presentations.

1. Type of Network

Different standard network topologies exist including token ring, star, mesh and bus as seen in Table 3.1.

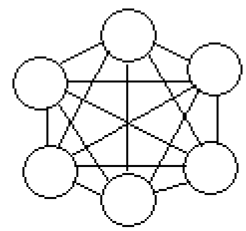
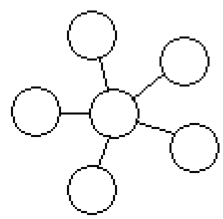
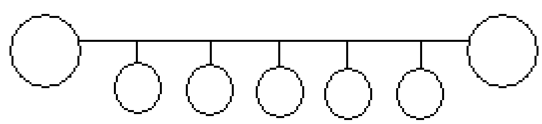
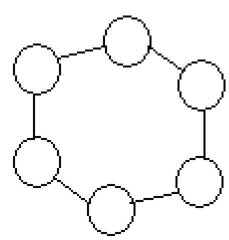
Mesh Topology Devices are connected with many redundant interconnections between network nodes. In a true mesh topology every node has a connection to every other node in the network.	
Star Topology All devices are connected to a central hub. Nodes communicate across the network by passing data through the hub.	
Bus Topology All devices are connected to a central cable, called the bus or backbone.	
Ring Topology All devices are connected to one another in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side of it.	

Table 3.1 Network Topologies (From Ref. 15)

Each topology has its advantages and disadvantages. The mesh network has an ideal peer-to-peer setup but because the system must be multi-media capable, the mobile devices currently do not have enough processing power to repurpose content by themselves. The star topology has the server in the center receiving and transmitting information, however, it does not have the resiliency if the server is damaged to continue transmitting data. The bus and ring topologies are not resilient enough to damage and so they would not be ideal choices for this DC network.

After examining the different types of networks, the best network available today would be a hybrid of the mesh and star network topologies. Because the server can repurpose data and timestamp information, the information should flow there first, however, if the server is damaged then the other nodes must continue to operate in a degraded status.

2. Data Transmission Medium

In the system requirements listed at the beginning of this chapter, some of the key requirements include mobility and scalability. So the best current commercially available alternative is 802.11 because running a wired network is not easily scalable and users have a difficult time being mobile if tethered by a wire. Benefits of WLAN are listed in Chapter II.

As part of this system, the ship will have WAPs throughout the ship so that users can input their information from almost anywhere onboard the ship. This information will instantaneously update everyone involved vice the minutes it takes currently to get through all the command and control points. Thus it is faster than the grease pencil and voice method used today discussed in the background information in Chapter II section A.

The system must be able to support a varying number of users. Revisiting the DC organization chart from Chapter Two again in Figure 3.2, we see that the number of potential users aboard a destroyer sized ship can vary from twenty for a small casualty to up to 90 for a major casualty.

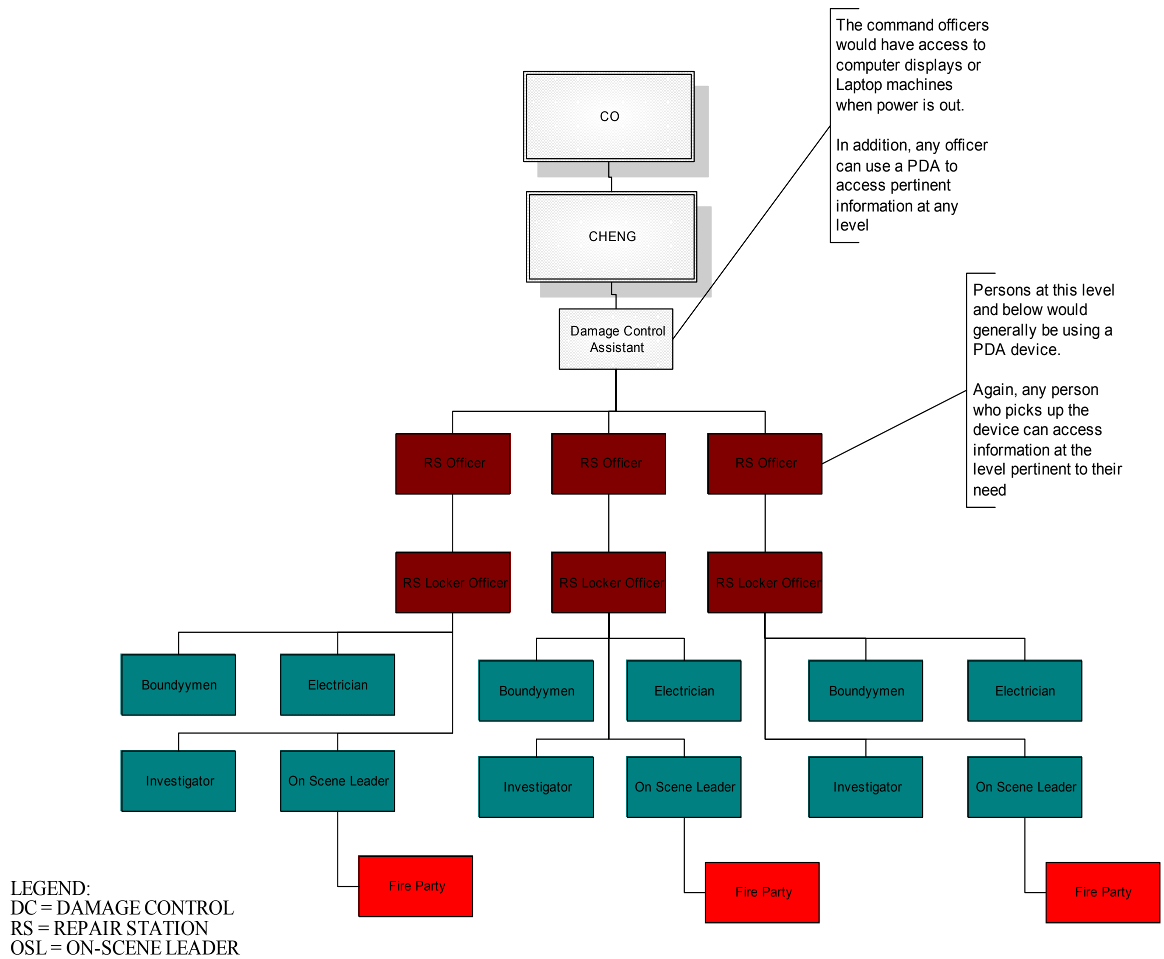


Figure 3.2 DC Organization

All of the major decision makers, from the CO down to each RS Officer, will need to be connected into the network. Additionally, the On-Scene Leader, Investigator, Electrician, and a member of the Fire Party from each RS should be connected to the LAN. This multi-user system must be able to accommodate all of these users and their inputs. The chosen architecture must be able to accommodate all possible numbers of users.

3. Functional Diagram

Figure 3.3 is an example of an architecture where any mobile device can connect with the DC server which in turn will repurpose the content depending on the device profile and send the data to other computing devices attached to the network. Different users within the DC organization use different devices, based upon the function they perform. For example, the DCA will often use a laptop as it is more convenient for the work the DCA has to perform. On the other hand, an OSL requires the mobility a PDA gives in order to capture new content to send to the DCA.

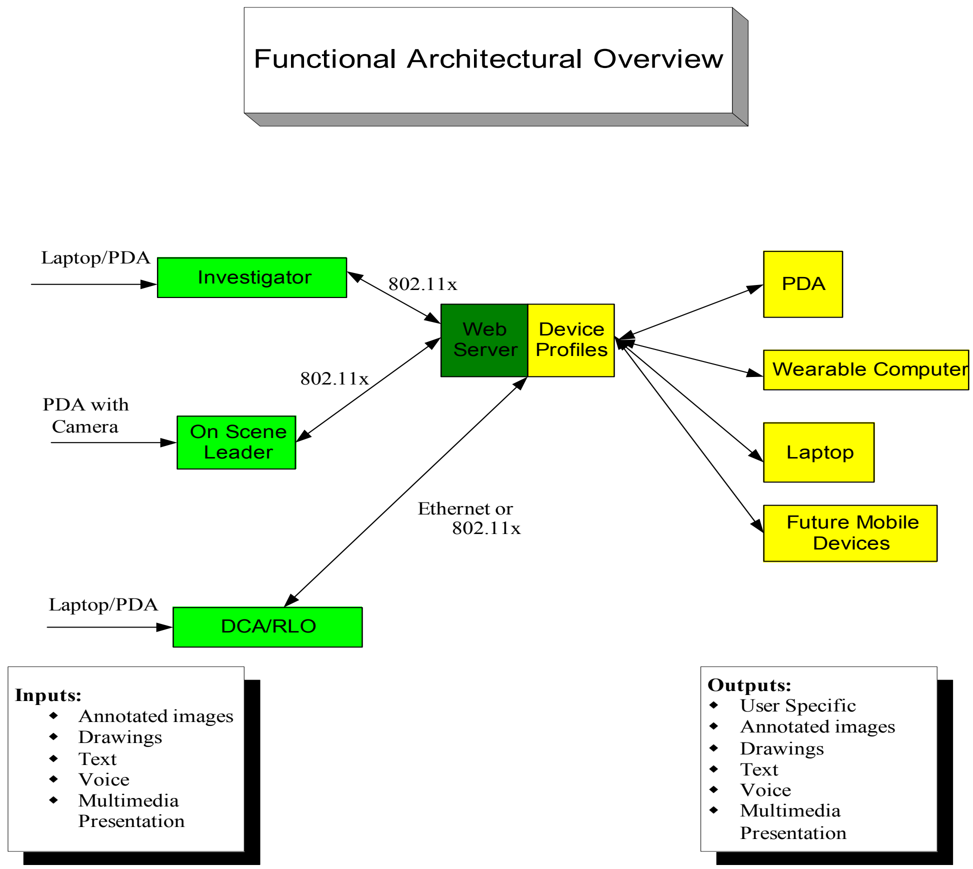


Figure 3.3 Functional Architectural Overview

D. SOFTWARE

Our goal is to implement an interactive, distributed application infrastructure with services represented as components with service interfaces.

1. Architectural Design

Our high level goals while designing the architecture are as follows:

-Code and design reuse: This reduces cost of new development and provides incremental quality improvements and establishes design best practices that everyone in the organization understands.

-Rational functional decomposition: Every class in the design plays a clearly defined role in the application. This clarity facilitates maintenance, impact analysis and system extension.
-Extensibility: The system should be easy to extend keeping up the growth of the organization.
-Modularity: Modular design helps maintainability and testability. It makes it easy to divide work within a team and provides opportunities to plug in new modules easily from either third parties or developed in house.
-Common look-and-feel: Helps users to use experience to navigate better while searching w for desired information or functionality. This also makes easier to add new user interfaces.
-Persistent data should always be consistent: The system design fulfils the above goals by using Model-View-Controller design pattern to separate form, function and data to divide into multiple tiered, functional modules. Model– View- Controller is a design pattern derived from the Smalltalk computer language. It is designed to change the User Interface without having to change much of the code for the program [16].

2. Java

Java is the language of choice for this system. Reasons for this choice include the number of devices that can be added to the system. Java's portability and ease of adaptability make it easier to adapt the code for different incoming devices. Java also works well with web browsing which will be the normal standard interface for applications in this system. Java is also an object oriented programming language, making the use cases mentioned above easier to implement.

This high-level Unified Modeling Language architecture in Figure 3.4 is a solid foundation for future projects in this area if using Java:

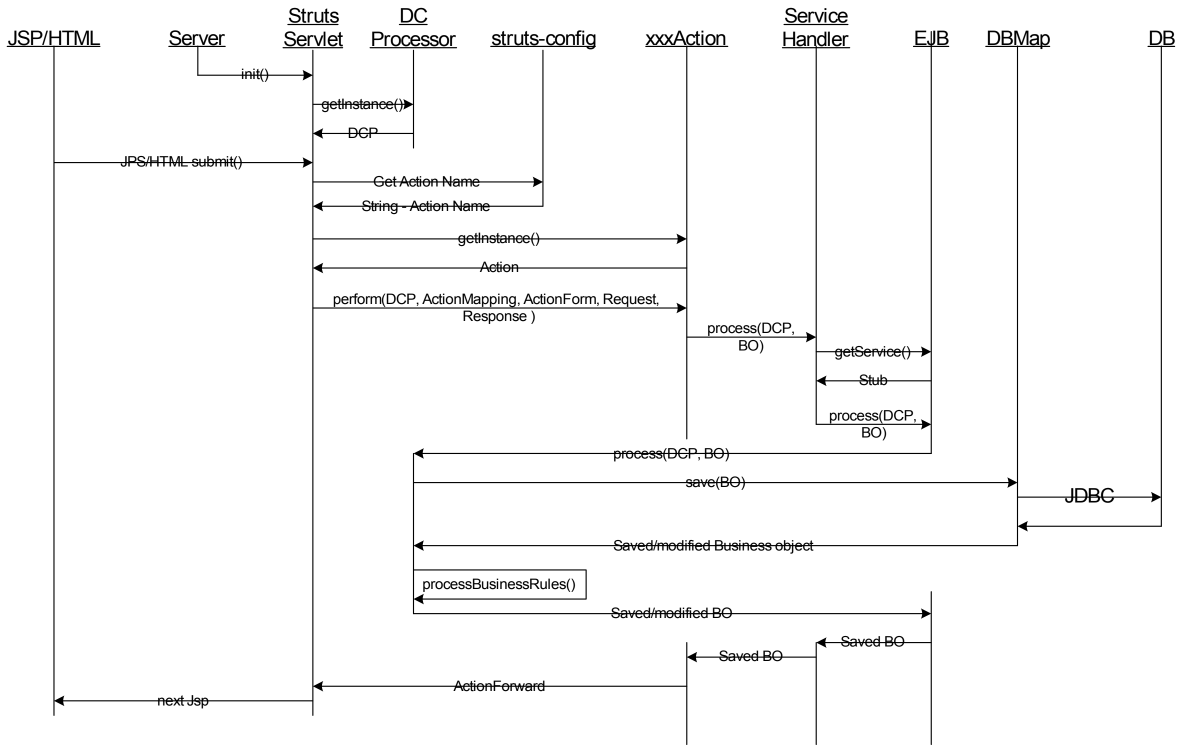


Figure 3.4 UML Architecture of DC Network Using Java

E. HARDWARE

This section discusses the hardware system design for shipboard implementation.

1. Design Criteria

This system must meet all of the following criteria during extreme circumstances such as loss of power to the ship's electrical system or loss of communications between areas of the ship:

Resiliency
802.11b wireless access
1000 BaseT(Gigabit)backbone network.
Compliance with standards
Construct with COTS components
Mobility
Security

2. Physical Layer

US Navy ships have specific issues for WLANs that must be addressed that are rarely, if ever, faced in the commercial world:

- -Problem of wireless communication within a steel structure
- -Problems related to EMI/RFI emissions such as Operational Security
- -Network loads and bandwidth utilization
- -Survivability of the network during conditions which are likely to arise during battle, such as an extended power outage, shock from explosions, heat from fires and water from flooding.

In Figure 3.5, one recommended hardware architecture design is presented. It meets the requirements mentioned previously in this section about resiliency and the ability to transmit enough information to and from users. The red line across the middle demonstrates the redundancy because if one portion of that network were to be destroyed or cut off from the rest of the network, the other side will continue to operate autonomously. The only problem with this architecture is the timeline could be skewed from actual events while part of the system was not operational.

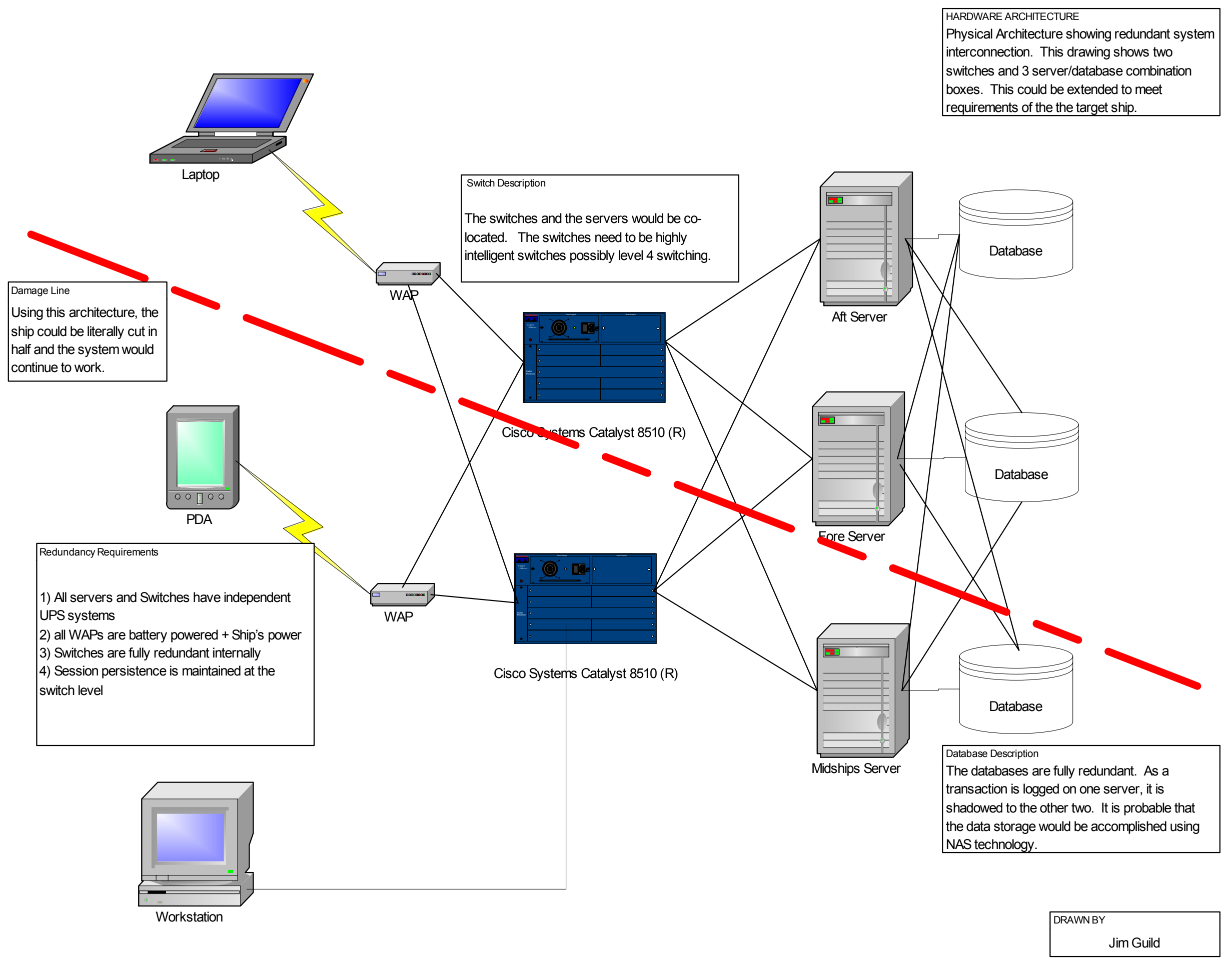


Figure 3.5 Hardware Design for DC Network

WAPs only have approximately 300 ft range in normal conditions. When onboard a Navy ship, the steel structures often act as a waveguide and prevent signals from propagating effectively and creating multi-path effects. Another way to solve this problem is to place a specially designed wireless repeater or access point on each of the bulkheads adjoining another compartment we can create the appearance of a continuous network throughout the ship. The 802.11a standard would be the best suited protocol for these WAPs due to possible interference in 802.11b transmissions. 802.11a has separate distinct channels which is better suited for multiple users whereas 802.11b channels overlap each other which could lead to interference. Also, 802.11a transmissions have a higher data rate which is needed for applications such as video streaming. However, further research is needed since this alternative may not be cost effective because of the extra WAPs needed, and the extra WAPs might cause other issues with operational security, although 802.11a does have a shorter transmission range. Also, this would be a problem since Sony currently does not have a wireless card that supports 802.11a.

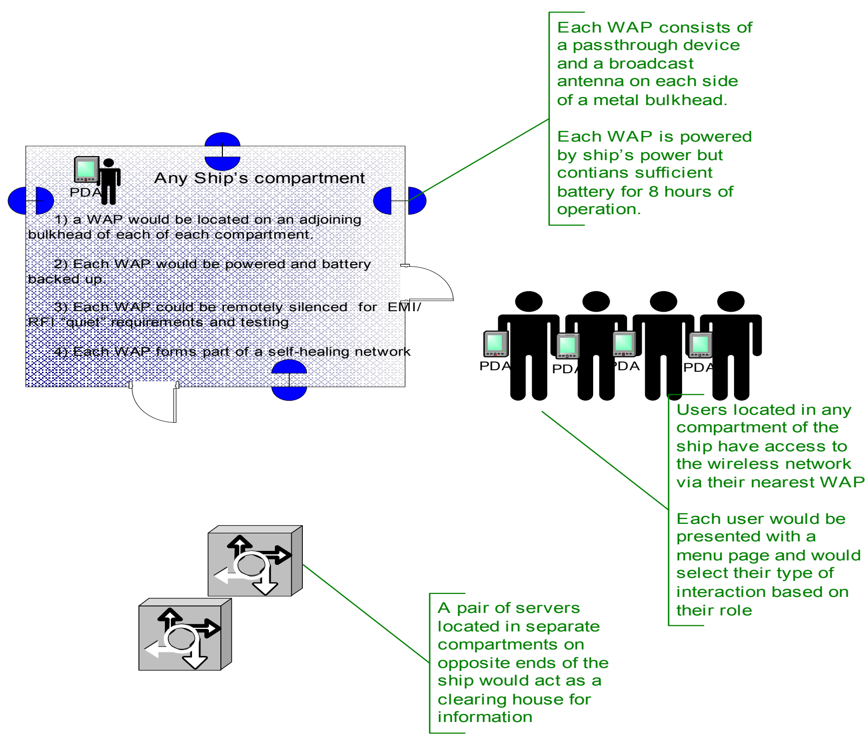


Figure 3.6 WAP Solution to Combat Multipath Effects

The wireless repeaters must be capable of operating on battery backup for at least eight hours of operational time due to the lengthy nature of certain DC situations such as mass conflagration. The redundancy built into this architecture allows continued connectivity even in the worst case scenario, which is shown in Figure 3.7. This shows a mass conflagration situation onboard a US Navy ship, showing how quickly a DC situation can move from bad to worse. This diagram shows three repair stations with three separate fire fighting activities being managed simultaneously by the DCA. Such scenarios require the system to have sufficient redundancy built into it such that if the aft portion of the ship has lost electrical power, then the forward portion of the ship will still be hooked into the network and DC operations can continue.

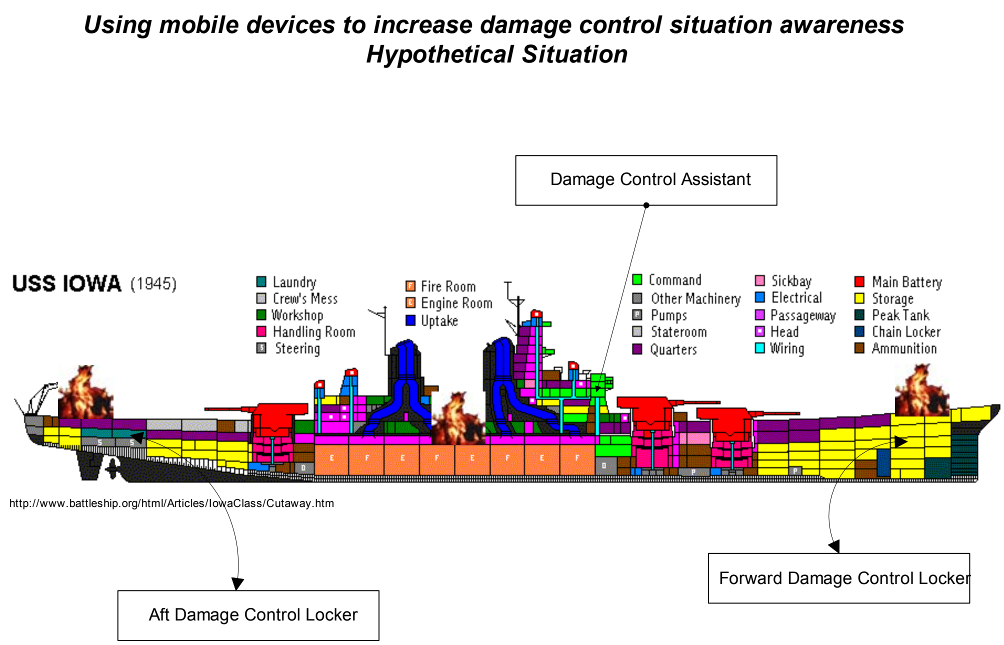


Figure 3.7 Example of ship during mass conflagration

So, now the situation with the mobile devices and WLAN installed aboard ship, yields different results than the antiquated status quo. Once a casualty was to occur, DC personnel would go through their standard operating procedures. The investigators would go and take pictures of the damage and then send out those annotated jpegs back to the server. The server would take those images and repurpose them to send out to the other devices on the network. Other DC members would use their devices to make their reports such as manned and ready and the fire being contained. The devices would also be used to respond to orders sent from superiors. Instead of having to send the communications verbally through all the command and control nodes, the information would appear near real-time at each node. The OSL could also use the camera to video conference with other DC leaders once protocol and bandwidth issues are resolved. This data transmission would also go back to the server and be repurposed depending on whether the video conference was going to a PDA or a laptop. Errors in verbal and written miscommunication would then be less likely to occur due to computer inputs.

The next chapter will focus on the human factors issues when mobile devices are used and discuss some research results from a survey posted to US Navy personnel involved in Damage Control.

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IV. HUMAN FACTORS

A. INTRODUCTION

Human factors considerations are key to developing successful systems but often they are neglected by developers. Rarely does testing and evaluation of a system only go beyond its hardware and software. Considerations such as anthropometric characteristics (i.e., human physical dimensions), sensory factors (i.e., sight, hearing, etc.), physiological factors (i.e., impact from environmental forces), psychological factors (i.e., needs, expectations, attitude, motivation, etc), and their interrelations are very important [14] but not considered often enough.

The purpose of this chapter is to highlight the human factors unique to using mobile devices in a DC environment. This is a broad overview and further research will be needed to determine human factors design criteria for future devices and training users with these devices to optimize usage.

B. HUMAN FACTORS AND DC

Figure 4.1 shows a possible flow of task considerations among hardware, software, and the user.

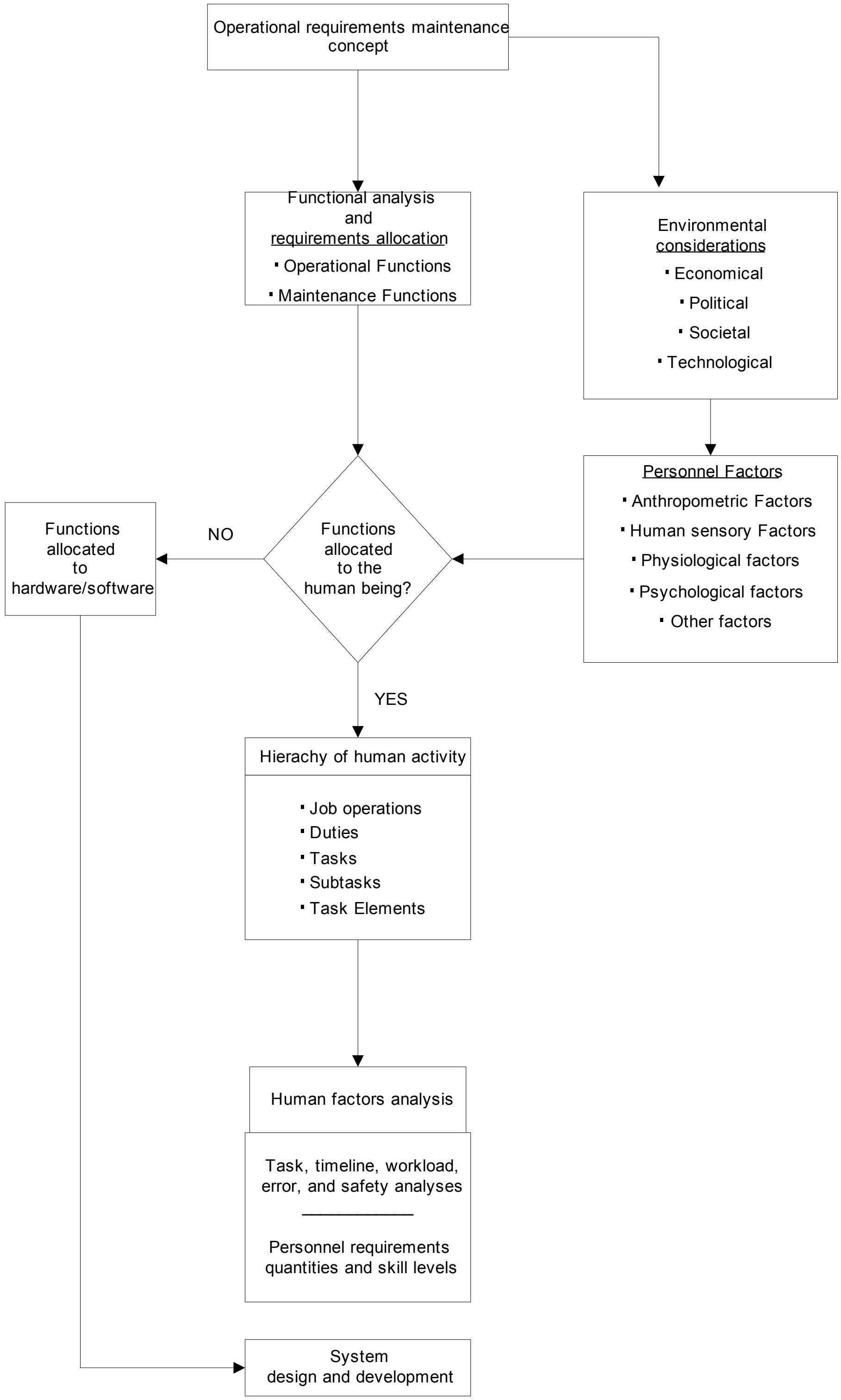

Figure 4.1 Human factors requirements (From Ref. 14)

Human factors play an important role in such a time-sensitive task like DC. The only way to reduce this stress is to practice the critical events with repetition so that these actions become second nature to the DC personnel.

1. Sensory Factors

Vision and Hearing play the two most important roles in the human-machine interface for system design [14].

Vision or sight, when determining proper system design, is a very important sensory capability. In normal situations, humans have 95 degrees vision to either side peripherally but the optimum is 15 degrees [14]. When wearing a breathing apparatus, a person’s sight is restricted peripherally. The mask of a breathing apparatus restricts a person’s peripheral vision to approximately 60 degrees to either side. So for maximum effectiveness, the device used for this system should be within the user’s optimum vision line.

Vision is stimulated by the electromagnetic radiation of certain wavelengths in the visible portion of the electromagnetic spectrum [14]. The eyes see different lines with varying degrees of brightness. When looking at colors, one can see all colors while looking straight ahead. As viewing angles begin to decrease, color perception begins to decrease horizontally and vertically [14]. Therefore, when using the mobile device, ensure the device is within the optimum tolerances from line of sight for most effective utilization.

One solution is to create a device that would project the screen of the PDA magnified on to the mask of the breathing device. Currently, a product exists where a projection attachment will put the screen of an attached PDA on to the lens of glasses [16]. This is in the beginning stages of development, though it looks viable commercially within the next year or two. Also, another option is Harmless Hazards Training has created a standard breathing apparatus outfitted with an advanced visualization display [17].

The other sense that human's mainly rely upon is hearing. Noise can be a distracter and interfere with work accomplishment [14]. Noise is an important factor when entering spaces such as an engine room that routinely have equipment that produces noise over 100 dB. This proposed computer network allows users to function without verbal communication in such environments. Information can be exchanged using camera, annotations or textual means via the mobile device. This way, other users may receive incoming messages without having to filter extraneous noise from the message as with current procedures.

2. Physiological Factors

Stress refers to any aspect of external activity or environment acting on the individual (who is performing system tasks) in such a manner as to cause a degrading effect [14]. Some causes of stress include temperature extremes, humidity, vibration, noise, and other factors.

Temperature extremes are detrimental to work efficiency. As temperature increases above the comfort zone (e.g. 55 to 75 degrees F), mental processes slow down, motor responses slow, and the likelihood of error increases [14]. The designer must make applications and devices simple to use because of the high temperature extremes that the DC personnel must deal with when in firefighting ensembles where space temperatures may be over several hundred degrees Fahrenheit.

The consequences of noise and impact on human efficiency were listed under sensory factors but mentioned again because high steady or intermittent levels of noise may have a highly degrading effect on human performance [14].

Devices used in the system must be able to withstand heat, salt, water, and should be rugged enough to withstand heavy impacts. The device must also have sufficient illumination to be usable even in thick smoke. In the extreme situations, the device should be able to float, allowing retrieval if dropped in water.

C. WIRELESS USE RULES

Research has shown that there is a range of recurring interaction rules unique to wireless use [15]:

- -Immediacy. Wireless solutions need to address an immediate need in an immediate fashion.
- -Locality. Despite being a global infrastructure, wireless use is dominated by local objectives.
- -Performed Use. Ease of use is important but also how do I look when using the device.
- -Personal & Work. To be able to use the device in both portions of a persons life.
- -Nomadic Trade-off. Difference between being in one place versus being mobile.
- -Connectivity. Being away from people, however, being able to connect with them at any time.
- -Human-in-Context Interface. Desire to include surroundings or others within the communication.

From the above list, immediacy and nomadic trade-off apply to this DC WLAN. When using a wireless product, the user demands efficiency and speed from the user interface. Otherwise, the user thinks time is being wasted and information is not being transmitted. Nomadic trade-off is the differences that users experience between a desktop versus a mobile environment. Users must realize that the mobile devices can do a lot but they are not desktops. They do not have all of the functions that a desktop has and they have to leave that paradigm.

D. ISSUES WITH USING MOBILE DEVICES

The purpose of this section is to discuss the current limiting factors of using mobile devices.

Screen size of the Sony Clie is 5.5 inches. It may seem too small to people used to large desktop displays. However, as mentioned in the sensory factors section of this chapter, where appropriate, a visor that projects the screen of the PDA on a head-mounted display maybe used.

Battery life of PDAs is relatively short. This means many Lithium Ion battery back-ups would be needed. Experience shows when using the Sony Clie in only the camera mode have resulted in less than one hour of battery life. Combining that with a connection to an 802.11b WLAN drains even more battery power. To be effective, battery life must be at least eight hours while using all of the capabilities. As new battery technology becomes commercially available, we expect the battery life to improve.

We found Sony Clie to be the best device for our project that requires multimedia information to be exchanged. Other devices had to install a camera through a compact flash card slot or add a wireless card. The size and weight of the Sony Clie are also quite suitable for use in DC applications. However, the PDA is fragile and when the system is installed onboard Navy ships, it must become more ruggedized. It can be encased in a rugged casing or jacket to make it withstand the tough ship environment.

E. FUTURE RESEARCH IN HUMAN FACTORS

More testing should be done with DC trainers and fire fighting trainers to see how personnel will react to many stimulants and also to practice using mobile devices in different scenarios. This will also help to test the mobile device to ensure that the form factor and applications are best suited for any DC emergency. A wrist mounted mobile device maybe a better form factor for DC users for certain types of activities. Other avenues include more research in the area of the PDA screen being magnified on the mask of the breathing device. Also, flexible organic light emitting displays (FOLEDs) may be a future option for the screens of mobile devices.

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V. CONCLUSION

A. SUMMARY

Despite the tremendous popularity of handheld devices and wireless networking, their utility is quite limited. There are several thousand PDA applications available in the market but users use only a handful of these. With the proper application focus and design, PDAs and wireless networking can be put to a much better use. In developing the DC architecture and application, special attention was paid to the following:

- *Improved communication* – Currently sound-power phones are the primary mode of communication. Given the gear the DC personnel have to wear and the ambient noise due to the damage, it is difficult and uncomfortable to use the radios. The DC personnel have to speak loudly and repeat themselves many times to be heard and understood. In addition to the physical difficulty of verbal communication, it is very difficult to convey certain types of information. This system improves the status quo by using a multimedia device, capable of capturing live images, enabling annotations and real-time delivery to the point of control. This overcomes many of the problems of the current systems.

- *Better situational awareness* – Currently grease pencils are used to mark positions and damage on paper sheets and laminated drawings in DC Central. This is based on the information received via sound-powered phones up a long chain of nodes. This information is then communicated to the various DCRSs via sound and marked laminated sheets. In this system, all information is conveyed in multimedia through the use of wireless. This completely eliminates the difficulties of the current systems and provides a much better situational awareness for all involved in DC operations.

- *Enhanced safety* – In today's DC situations, several fire and smoke containment boundaries have to be violated due to the use of sound-power lines. This increases the chances of spread of damage. In addition, the information of hazards or other important property in the vicinity (such as storage of explosives or other flammable materials, and location of personnel) is difficult to communicate to the DC personnel. Given that our system uses wireless networking, fire and smoke containment boundaries do not have to be violated. In addition, since maps and sketches can be shared in the team, location of hazards can be easily identified and conveyed.

This project has presented an architecture for a multi-device DC WLAN. The system is scalable, multi-user, wireless, mobile, and multi-device. Other advantages of our system include that it can be implemented using COTS equipment leading to low cost and inexpensive to maintain. It can also be employed for other uses such as allowing ship's supply personnel to inventory items wirelessly using other mobile devices. Also, more engineering equipment could be tracked through the WLAN like the experiment onboard USS HOWARD (DDG-83) mentioned in Chapter II.

After researching the available PDAs on the market, the Sony Clie seemed to be the best commercially available device for this project. The product had a voice recorder, built-in camera, 802.11b card, and a video recording capability.

There are some disadvantages associated with this system. Security is a large issue for wireless communications. Until the US Navy is confident that the system will be secure from electromagnetic radiation detection and also not easily hacked, it will not install any WLANs on to its warships. Also, there is currently no device that meets the demands of DC personnel especially in terms of heat, water, and ruggedness. Battery life of the mobile device is a major issue. Cost to initially fund the system could be relatively high due to the effects of multi-path fading onboard ships. The reason for this being the large number of access points needed. However, a design for a new type of access point was offered in Chapter III in the hardware requirements section as a possibility for effectively covering the ship.

B. FUTURE RESEARCH

In the current version of our system, we are using existing technology to develop an application that addresses some of the most difficult challenges for damage control application onboard Navy ships. In the near future, a screen magnification system can be integrated into the mask of the breathing apparatus. This way the OSL would not constantly have to look down at the PDA screen and strain their eyes in a highly stressful situation. Another reason for having the magnified screen onto a mask will be that the PDA screen size is normally too small for the OSL to use. The display has to be easy to use and see all the new information that is being transmitted. If the display were on the face of the mask, personnel would not have to try to look at the screen in darkness or through the smoke of the fire. Also, alternate ways of providing input should be explored so that stylus input does not have to be used all the time. The stylus is too hard to use when using gloves or when the user's hands are wet either from perspiration or water.

C. CONCLUSION

The possibilities of utilizing WLANs and mobile devices for DC are just beginning. Much more testing can and should be done. The overall benefits of PDAs and wireless networks will drive the military to continue experimenting and fielding systems that will greatly improve the status quo.

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